Project Report

ETS-6

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The Handling and Uses of the SAO Catalog

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LEXINGTON, MASSACHUSETTS

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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Group 94

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ABSTRACT

The complete and rigorous update procedures applied to the 1950.0 epoch SAO Catalog are described. The corrections included are the terms of elliptic aberration, precession, proper motion, and foreshortening (e.g., parallax and radial velocity terms). The uses of the updated catalog are schematically described for the local reduction of artificial satellite positions. Finally, an annotated FORTRAN program is included.

I. INTRODUCTION

This report describes the sequence of computations performed to update the Smithsonian Astrophysical Observatory Catalog (SAO[3]; hereinafter the SAOC) from epoch 1950.0 to the present. We also schematically describe the use of a current version of the SAOC in reducing artificial satellite positions and photometry. The reader should be familiar with Taff[4]. Also, Taff (in press[5]) discusses photometric reductions. Finally, the reader should be aware that the errors discussed in § VIII of Taff[4] are reduced by a factor of two when proper treatment of the e-terms is included.

Sections III and IV detail the update calculations performed on the SAOC and Section V describes the astrometric information contained in the 1975.0 master and subsequent yearly tapes.

II. DESCRIPTION OF THE SAOC

The SAO, in response to the needs of the space age, constructed a non-fundamental, astrometric, compilation catalog with the following goals: (1) the star density would be at least four stars per square degree, (2) the 1970.0 positions would have a root mean square error of $\leq 1''$, and (3) the catalog would be on the FK4 system. The physical existence of the SAOC and reference to Haramundanis[1] and Scott and Smith[2] indicate that these goals have been met.

The catalog contains entries for 258,997 stars. For astrometric purposes the most important aspects of the SAOC are its success in meeting the above goals and its availability in machine readable form. For our purposes the most important datum for each star consists of position (α = right ascension, δ = declination) and proper motions (μ = proper motion in right ascension, μ' = proper motion in declination). This information is in a barycentric solar system coordinate system for the equator and equinox of 1950.0. The reader is referred to the Introduction of the SAOC. However, he should be aware that the σ_{1950} column is totally incorrect and although the wrong equations appear on p. xiii for σ_{μ} and $\sigma_{\mu'}$, the correct formulas were used in their computation.

III. ELLIPTIC ABERRATION

The position (e.g., α, δ) of a star, referred to a mean equator and equinox of date, is referred to as a mean position. It differs from the true position (at that time in that coordinate system) by the effects of nutation. However, because the eccentricity of the earth's orbit is small and hand computation laborious, it has been traditional to leave in those observational effects due solely to the ellipticity of the earth's orbit in the just defined mean place. Catalogs contain mean places of stars. Let $[\alpha_o(t'), \delta_o(t')]$ be the just defined mean place at epoch t' as found in a catalog. Then the real (i.e., intrinsic) position $[\alpha(t'), \delta(t')]$ is obtained by setting

$$\alpha(t') = \alpha_o(t') - \Delta\alpha(t'), \tag{1a}$$

$$\delta(t') = \delta_o(t') - \Delta\delta(t'). \tag{1b}$$

The e-term corrections are given by

$$\Delta\alpha(t') = c\Delta C + d\Delta D, \tag{2a}$$

$$\Delta\delta(t') = c'\Delta C + d'\Delta D, \tag{2b}$$

where the Besselian star constants c, d, c', d' are given by

$$c = \cos\alpha_o(t')\sec\delta_o(t'),\ d = \sin\alpha_o(t')\sec\delta_o(t'), \tag{3a}$$

$$c' = \tan\varepsilon(t')\cos\delta_o(t') - \sin\alpha_o(t')\sin\delta_o(t'),$$

$$d' = \cos\alpha_o(t')\sin\delta_o(t'), \tag{3b}$$

where ε is the true obliquity of the ecliptic at $t = t'$. The quantities ΔC and ΔD are computed from ε, the constant of aberation $\kappa(= 20''.4958)$, the eccentricity of the earth's orbit e, and the longitude of the earth's perihelion ω. Thus,

$$\Delta C = e(t')\kappa\cos\omega(t')\cos\varepsilon(t') \tag{4a}$$

$$\Delta D = e(t')\kappa\sin\omega(t'), \tag{4b}$$

where

$$e = 0.01675104 - 4.18 \times 10^{-5}T - 1.26 \times 10^{-7}T^2, \tag{5a}$$

$$\varepsilon = 23^\circ 27' 8''.26 - 46''.845T - 0''.0059T^2 + 0''.00181T^3, \tag{5b}$$

$$\omega = 101^\circ 13' 15''.0 + 6189''.03T + 1''.63T^2 + 0''.012T^3, \tag{5c}$$

and T is the number of tropical centuries elapsed since 1900.0.

From Eqs. (5) it is clear that e, ε, and ω vary very slowly and that $e\kappa$ is a small number. Hence, these corrections are generally minute. In fact, it can be shown that if $t' = 1950.0$, $t'' = 1975.0$ then the absolute value of the maximum errors in $\alpha(t'')$ and $\delta(t'')$ due to neglect of the e-terms are $2''.11 \times 10^{-3}\sec^2\delta(t')$ and $0''.97 \times 10^{-3}\sec\delta(t')$. The errors are linear in $t'' - t'$.

However, as is the case with most approximations used in spherical astronomy, the neglect of the e-terms produces an effect in right ascension that systematically increases with declination. Therefore, since these right ascensions are necessarily of poorer accuracy than those at lower declinations, the first

step in updating the SAOC is to apply Eqs. (1). The second step is discussed below (§ IV). The third step is to add back in $\Delta\alpha(t'')$, $\Delta\delta(t'')$.

IV. PRECESSION AND PROPER MOTION

Using $\alpha(t')$ and $\delta(t')$ [along with $\mu(t')$ and $\mu'(t')$] as input, the power series method of Taff[4] was then applied from $t' = 1950.0$ to $t'' = 1975.0$. The complete details are in § III of that report. The Appendix contains an annotated listing of a thoroughly tested FORTRAN program to perform <u>all</u> of the computations discussed herein.

While only minor typographical errors have been discovered in Taff[4], the algebraic reduction which yielded Eqs. (14a, b) is sufficiently complicated that the unsimplified versions are used in the program.

V. THE LINCOLN 1975.0 YEARLY VERSIONS OF THE SAOC

After a complete reduction had been performed to 1975.0 a new SAOC tape was constructed at Lincoln. It contains for epoch 1975, α, δ, μ, μ', $d\alpha/dt$, $0.5d^2\alpha/dt^2$, $d\delta/dt$, $0.5d^2\delta/dt^2$, $d\mu/dt$, and $d\mu'/dt$. In addition, depending on $\delta(t')$ (relative to $\pm 80^{\circ}$), either 1950.0 $0.5d^2\alpha/dt^2$, $0.5d^2\delta/dt^2$, $d\mu/dt$, and $d\mu'/dt$ or the same quantities at 1970.0. The tape has been resorted into 10° wide declination bands with right ascension increasing in each band.

For each year the 1975.0 tape is updated (on or about 1 July) to provide positions and proper motions whose epoch is that of nearest Besselian solar year. This update is performed using Eqs. (18, 19) or (20, 21) of Taff[4].

VI. USES OF THE SAOC

The primary use of the SAOC is in the precise reduction of artificial satellite positions and photometry. For this purpose an interactive graphics display program exists. The operator (or computer) enters the right ascension and declination of interest, the size of the surrounding area to be displayed (up to 5°), and either the star density per square degree (with the brightest stars used first) or a magnitude limit. The program then generates a display of the appropriate star field including differing intensities for the stars. The position of the telescope and the satellite in question are also indicated. As the real time pointing system provides information on telescope motion, it is a simple task to continually update the display, look backward in time, or look forward in time. A local calibration procedure will be used to simultaneously reduce the position and photometry of the satellite.

APPENDIX: LISTING OF FORTRAN PROGRAM

Following this text is a complete listing of the two subroutines used to update the SAOC. In particular the epochs 1950.0, 1975.0, and 1977.0 appear explicitly in the program (e.g., within DO loops #1, #2; above statement #4; the IF statement below statement #5; at statement #6; at statement #14; and below statement #15). Quantities such as R(I), RA, ALP refer to right ascension; D(I), DEC, DEL refer to declination; MU, MUA refer to proper motion in right ascension; MUP, MUD refer to proper motion in declination; DA, EA to $d\alpha/dt$, etc. Trigonometric functions of an angle are usually prefixed, thus CO is the cosine of omega, TD the target of declination, etc. With close reference to Eqs. (7-21) of Taff[4] the reader should have no difficulty following the program.

```
      SUBROUTINE UPDATE(R(1),D(1),MU(1),MUP(1),R(6),D(6),MU(6),MUP(6))
C    RIGOROUS PRECESSION & PROPER MOTION UPDATE/POWER SERIES METHOD
C INPUT ARE VARIABLES AT INDEX 1, OUTPUT ARE VARIABLES AT INDEX 6
C PRECISION NEEDED IS 10.**(-9) FOR ALL OPERATIONS
      IMPLICIT DOUBLE PRECISION (A-H,M-Z)
      DOUBLE PRECISION KAP
      INTEGER HR,DEG,MINT,MINA
      DIMENSION R(6),DA(6),D2A(6),D(6),DD(6),D2D(6),MU(6),DMU(6),MUP(6),
     *DMUP(6),M(6),MP(6),N(6),NP(6),TE(2),DELC(2),DELD(2),PHOT(11)
      COMMON /DERIV/DA75,D2A50,D2A75,DD75,D2D50,D2D75,DMU50,DMU75,
     * DMUP50,DMUP75
      COMMON/DAT/PI2,PI,TPI,T,FT,TWT
C SET UP CONSTANTS
      DATA KAP,CON,IP,IM/2.04958D1,1.02269D-4,'+   ','-   '/
      PI=3.1415926536D0
      PI2=5.D-1*PI
      TPI=PI+PI
      CRA=PI/4.32D4
      CDEC=PI/6.48D5
      PI12=PI/1.2D1
      PI180=PI/1.8D2
      OS=1.D0/6.D1
      TWT=2.D1/3.D0
      FT=4.D0/3.D0
      DMAX=8.0D1*PI180
C IF PARALLAX AND RADIAL VELOCITY UNKNOWN SET THEM EQUAL TO ZERO
      PAR=0.D0
      VR=0.D0
C SET UP PRECESSION CONSTANTS
      DO 1 I=1,6
      T=5.D-1+5.D-2*(I-1)
      M(I)=CRA*(3.07234D2+T*(1.8630D-1+T*8.D-6))
      MP(I)=CRA*(1.8630D-1+T*1.6D-5)
      N(I)=CDEC*(2.004685D3-T*(8.533D-1+T*3.7D-4))
    1 NP(I)=-CDEC*(8.533D-1+T*7.4D-4)
      MPP=CRA*1.6D-5
      NPP=-CDEC*7.4D-4
C SET UP ELLIPTIC ABERRATION CONSTANTS
      DO 2 I=1,2
      T=5.D-1+2.5D-1*(I-1)
      OME=PI180*(1.01D2+OS*(1.3D1+OS*(1.5D1+T*(6.18903D3+T*(1.63D0+T*1.2
     *D-2)))))
      CO=DCOS(OME)
      SO=DSIN(OME)
      EPS=PI180*(2.3D1+OS*(2.7D1+OS*(8.26D0-T*(4.6845D1+T*(5.9D-3-T*1.61
     *D-3)))))
      CE=DCOS(EPS)
      TE(I)=DTAN(EPS)
      ECC=1.675104D-2-T*(4.18D-5+T*1.26D-7)
      DELC(I)=CDEC*KAP*ECC*CO*CE
    2 DELD(I)=CDEC*KAP*ECC*SO
C INPUT IS     RA AND DEC IN RADIANS; MU,MUP IN RAD/CENT; PAR IN SECONDS
C OF ARC, VR IN KM/SEC
C DETERMINE DECLINATION RANGE
      L=5
      IF(DABS(D(1)).GT.DMAX) L=1
C ADJUST RA AND DEC FOR E-TERMS
      SR=DSIN(R(1))
      CR=DCOS(R(1))
```

```
      SD=DSIN(D(1))
      CD=DCOS(D(1))
      R(1)=R(1)-(CR*DELC(1)+SR*DELD(1))/CD
      D(1)=D(1)-((TE(1)*CD-SR*SD)*DELC(1)+CR*SD*DELD(1))
      T=5.D-2*L
C INITIALIZE COUNTER
      K=1
C CALCULATE DRA/DT,D2RA/DT**2,D3RA/DT**3,DDEC/DT,D2DEC/DT**2,D3DEC/DT**3
C ,DMU/DT,D2MU/DT**2,DMUP/DT, AND D2MUP/DT**2 AT 1950.0
    4 SR=DSIN(R(K))
      CR=DCOS(R(K))
      TD=DTAN(D(K))
      SEC2=1.D0+TD*TD
      S2D=DSIN(2.D0*D(K))
      C2D=DCOS(2.D0*D(K))
      PR=M(K)+N(K)*SR*TD
      PD=N(K)*CR
      DA(K)=PR+MU(K)
      DD(K)=PD+MUP(K)
      DPR=MP(K)+NP(K)*SR*TD+N(K)*DA(K)*CR*TD+N(K)*DD(K)*SR*SEC2
      DPD=NP(K)*CR-N(K)*DA(K)*SR
      D2A(K)=5.D-1*(MP(K)+NP(K)*SR*TD+N(K)*(DA(K)+MU(K))*CR*TD+N(K)*(DD(
     *K)+MUP(K))*SR*SEC2+2.D0*MU(K)*MUP(K)*TD-2.D0*MU(K)*CON*PAR*VR)
      D2D(K)=5.D-1*(NP(K)*CR-N(K)*(DA(K)+MU(K))*SR-5.D-1*MU(K)*MU(K)*S2D
     *-2.D0*MUP(K)*CON*PAR*VR)
      DMU(K)=N(K)*MU(K)*CR*TD+N(K)*MUP(K)*SR*SEC2+2.D0*MU(K)*MUP(K)*TD-2
     *.D0*MU(K)*CON*PAR*VR
      DMUP(K)=-N(K)*MU(K)*SR-5.D-1*MU(K)*MU(K)*S2D-2.D0*MUP(K)*CON*PAR*V
     *R
      D3A=MPP+NPP*SR*TD+NP(K)*DA(K)*CR*TD+NP(K)*DD(K)*SR*SEC2+NP(K)*(PR+
     *2.D0*MU(K))*CR*TD+N(K)*(DPR+2.D0*DMU(K))*CR*TD-N(K)*(PR+2.D0*MU(K)
     %)*DA(K)*SR*TD+N(K)*(PR+2.D0*MU(K))*DD(K)*CR*SEC2+2.D0*DMU(K)*MUP(K
     &)*TD+2.D0*MU(K)*DMUP(K)*TD+2.D0*MU(K)*MUP(K)*DD(K)*SEC2+NP(K)*(PD+
     #2.D0*MUP(K))*SR*SEC2+N(K)*(DPD+2.D0*DMUP(K))*SR*SEC2+N(K)*(PD+2.D0
     $*MUP(K))*DA(K)*CR*SEC2+2.D0*N(K)*(PD+2.D0*MUP(K))*SR*TD*SEC2*DD(K)
      D3D=NPP*CR-NP(K)*DA(K)*SR-NP(K)*(PR+2.D0*DMU(K))*SR-N(K)*(DPR+2.D0
     **DMU(K))*SR-N(K)*(PR+2.D0*MU(K))*DA(K)*CR-MU(K)*DMU(K)*S2D-MU(K)*M
     %U(K)*DD(K)*C2D
      D2MU=MU(K)*NP(K)*CR*TD+MUP(K)*NP(K)*SR*SEC2+N(K)*(MU(K)*DD(K)+MUP(
     *K)*DA(K))*CR*SEC2+N(K)*(2.D0*MUP(K)*DD(K)*SEC2-MU(K)*DA(K))*SR*TD-
     %2.D0*SD*SD*MU(K)**3+N(K)*N(K)*MU(K)*(CR*CR*TD*TD-SR*SR*SEC2)+N(K)*
     &N(K)*MUP(K)*SR*CR*TD*SEC2+4.D0*N(K)*MU(K)*MUP(K)*CR*TD*TD+N(K)*(2.
     #D0*MUP(K)*MUP(K)*SEC2-3.D0*MU(K)*MU(K))*SR*TD+4.D0*MU(K)*MUP(K)*MU
     $P(K)*TD*TD+2.D0*MU(K)*MUP(K)*DD(K)*SEC2
      D2MUP=-MU(K)*NP(K)*SR-N(K)*MU(K)*DA(K)*CR-N(K)*N(K)*MUP(K)*SR*SR*S
     *EC2-N(K)*N(K)*MU(K)*SR*CR*TD-2.D0*N(K)*MU(K)*MU(K)*CR*SD*SD-4.D0*N
     %(K)*MU(K)*MUP(K)*SR*TD-MU(K)*MU(K)*(DD(K)+2.D0*(MUP(K)-PD)*SD*SD)
C OBTAIN ESTIMATES FOR RA,DEC,MU,MUP AT 1950.0+T
    5 RA=R(K)+T*(DA(K)+T*(D2A(K)+T*D3A/6.D0))
      DEC=D(K)+T*(DD(K)+T*(D2D(K)+T*D3D/6.D0))
      MUA=MU(K)+T*(DMU(K)+5.D-1*T*D2MU)
      MUD=MUP(K)+T*(DMUP(K)+5.D-1*T*D2MUP)
      SR=DSIN(RA)
      CR=DCOS(RA)
      TD=DTAN(DEC)
      SEC2=1.D0+TD*TD
      S2D=DSIN(2.D0*DEC)
C IF T =0.25 DONE
      IF(L.EQ.5) GO TO 14
C T=0.05: USING 1955.0,1960.0, ETC. ESTIMATES FOR RA,DEC,MU, AND MUP RE-
```

```
C CALCULATE D2RA/DT**2,D2DEC/DT**2,DMU/DT, AND DMUP/DT
      PR=M(K+1)+N(K+1)*SR*TD
      PD=N(K+1)*CR
      E2A=5.D-1*(MP(K+1)+NP(K+1)*SR*TD+ N(K+1)*(PR+2.D0*MUA)*CR*TD+N(K+1
     *)*(PD+2.D0*MUD)*SR*SEC2+2.D0*MUA*MUD*TD-2.D0*MUA*CON*PAR*VR)
      E2D=5.D-1*(NP(K+1)*CR- N(K+1)*(PR+2.D0*MUA)*SR-5.D-1*MUA*MUA*S2D-2
     *.D0*MUD*CON*PAR*VR)
      DMUA=N(K+1)*MUA*CR*TD+N(K+1)*MUD*SR*SEC2+2.D0*MUA*MUD*TD-2.D0*MUD*
     *CON*PAR*VR
      DMUD=-N(K+1)*MUA*SR-5.D-1*MUA*MUA*S2D-2.D0*MUD*CON*PAR*VR
C GET 1955.0,1960.0, ETC. RA,DEC,MU, AND MUP
      R(K+1)=R(K)+T*(DA(K)+T*(D2A(K)+TWT*T*(E2A-D2A(K))))
      D(K+1)=D(K)+T*(DD(K)+T*(D2D(K)+TWT*T*(E2D-D2D(K))))
      MU(K+1)=MU(K)+T*(DMU(K)+1.D1*T*(DMUA-DMU(K)))
      MUP(K+1)=MUP(K)+T*(DMUP(K)+1.D1*T*(DMUD-DMUP(K)))
C INCREMENT COUNTER
      K=K+1
C DONE?
    6 IF(K.EQ.6) GO TO 7
C NOT DONE, REPEAT UPDATE CYCLE
      GO TO 4
C PRECESSION AND PROPER MOTION UPDATE IS NOW DONE, UNDO E-TERMS
    7 SR=DSIN(R(6))
      CR=DCOS(R(6))
      SD=DSIN(D(6))
      CD=DCOS(D(6))
      R(6)=R(6)+(CR*DELC(2)+SR*DELD(2))/CD
      D(6)=D(6)+((TE(2)*CD-SR*SD)*DELC(2)+CR*SD*DELD(2))
C CALCULATE D2RA/DT**2,D2DEC/DT**2,DMU/DT, AND DMUP/DT AT 1975.0 FOR USE
C IN YEARLY UPDATE PROGRAM (TOYR)
      SR=DSIN(R(K))
      CR=DCOS(R(K))
      TD=DTAN(D(K))
      SEC2=1.D0+TD*TD
      S2D=DSIN(2.D0*D(K))
      PR=M(K)+N(K)*SR*TD
      PD=N(K)*CR
      DA(K)=PR+MU(K)
      DD(K)=PD+MUP(K)
      D2A(K)=5.D-1*(MP(K)+NP(K)*SR*TD+N(K)*(DA(K)+MU(K))*CR*TD+N(K)*(DD(
     *K)+MUP(K))*SR*SEC2+2.D0*MU(K)*MUP(K)*TD-2.D0*MU(K)*CON*PAR*VR)
      D2D(K)=5.D-1*(NP(K)*CR-N(K)*(DA(K)+MU(K))*SR-5.D-1*MU(K)*MU(K)*S2D
     *-2.D0*MUP(K)*CON*PAR*VR)
      DMU(K)=N(K)*MU(K)*CR*TD+N(K)*MUP(K)*SR*SEC2+2.D0*MU(K)*MUP(K)*TD-2
     *.D0*MU(K)*CON*PAR*VR
      DMUP(K)=-N(K)*MU(K)*SR-5.D-1*MU(K)*MU(K)*S2D-2.D0*MUP(K)*CON*PAR*V
     *R
C CHECK FOR OVER THE POLES OR AROUND THE VERNAL EQUINOX
      IF(DABS(D(6)).LT.PI2) GO TO 11
      R(6)=R(6)+PI
      IF(D(6)) 8,8,9
    8 D(6)=-D(6)-PI
      GO TO 10
    9 D(6)=PI-D(6)
   10 IF(R(6).GE.TPI) R(6)=R(6)-TPI
      IF(R(6).LT.0.D0) R(6)=R(6)+TPI
C OUTPUT
   11 RA=R(6)/PI12
      HR=RA
      RA=6.D1*(RA-HR)
```

```
      MINT=RA
      RA=6.D1*(RA-MINT)
      DEC=DABS(D(6))/PI180
      DEG=DEC
      DEC=6.D1*(DEC-DEG)
      MINA=DEC
      DEC=6.D1*(DEC-MINA)
      MUA=MU(6)/CRA
      MUD=MUP(6)/CDEC
      IS=IP
      IF(D(6).LT.0.D0) IS=IM
      WRITE(3,12) HR,MINT,RA,MUA,IS,DEG,MINA,DEC,MUD
   12 FORMAT(1X,2I3,F8.3,2X,F8.3,5X,A1,I2,I3,F7.2,2X,F7.2)
      GO TO 15
C USING 1975.0 ESTIMATES FOR RA,DEC,MU, AND MUP RECALCULATE D2RA/DT**2,
C D2DEC/DT**2,DMU/DT, AND DMUP/DT
   14 K=5
      PR=M(K+1)+N(K+1)*SR*TD
      PD=N(K+1)*CR
      E2A=5.D-1*(MP(K+1)+NP(K+1)*SR*TD+ N(K+1)*(PR+2.D0*MUA)*CR*TD+N(K+1
     *)*(PD+2.D0*MUD)*SR*SEC2+2.D0*MUA*MUD*TD-2.D0*MUA*CON*PAR*VR)
      E2D=5.D-1*(NP(K+1)*CR- N(K+1)*(PR+2.D0*MUA)*SR-5.D-1*MUA*MUA*S2D-2
     *.D0*MUD*CON*PAR*VR)
      DMUA=N(K+1)*MUA*CR*TD+N(K+1)*MUD*SR*SEC2+2.D0*MUA*MUD*TD-2.D0*MUD*
     *CON*PAR*VR
      DMUD=-N(K+1)*MUA*SR-5.D-1*MUA*MUA*S2D-2.D0*MUD*CON*PAR*VR
C GET 1975.0 RA,DEC,MU, AND MUP
      R(6)=R(1)+T*(DA(1)+T*(D2A(1)+FT*T*(E2A-D2A(1))))
      D(6)=D(1)+T*(DD(1)+T*(D2D(1)+FT*T*(E2D-D2D(1))))
      MU(6)=MU(1)+T*(DMU(1)+2.D0*T*(DMUA-DMU(1)))
      MUP(6)=MUP(1)+T*(DMUP(1)+2.D0*T*(DMUD-DMUP(1)))
C SET COUNTER TO END
      K=6
      GO TO 6
   15 CONTINUE
C TOYR SECTION
C HERE UPDATES 1975.0 TO 1977.0
      T=2.D-2
      DA75=DA(6)
      D2A75=D2A(6)
      DD75=DD(6)
      D2D75=D2D(6)
      DMU75=DMU(6)
      DMUP75=DMUP(6)
      L=6-L
      D2A50=D2A(L)
      D2D50=D2D(L)
      DMU50=DMU(L)
      DMUP50=DMUP(L)
      CALL TOYR(R(6),D(6),MU(6),MUP(6),RA,DEC,MUA,MUD,L)
C OUTPUT
      ALP=RA/PI12
      HR=ALP
      ALP=6.D1*(ALP-HR)
      MINT=ALP
      ALP=6.D1*(ALP-MINT)
      DEL=DABS(DEC)/PI180
      DEG=DEL
      DEL=6.D1*(DEL-DEG)
      MINA=DEL
```

```
      DEL=6.D1*(DEL-MINA)
      MUA=MUA/CRA
      MUD=MUD/CDEC
      IS=IP
      IF(DEC.LT.0.D0) IS=IM
      WRITE(3,12) HR,MINT,ALP,MUA,IS,DEG,MINA,DEL,MUD
   16 CONTINUE
      CALL EXIT
      END
```

```
      SUBROUTINE TOYR(ALP,DEL,MUA,MUD,RA,DEC,MU,MUP,L)
      IMPLICIT DOUBLE PRECISION (A-H,M-Z)
      COMMON /DERIV/DA75,D2A50,D2A75,DD75,D2D50,D2D75,DMU50,DMU75,
     * DMUP50,DMUP75
      COMMON/DAT/PI2,PI,TPI,T,FT,TWT
C INPUT IS ALP,DEL IN RAD; MUA,MUD IN RAD/CENT; T IN CENT
C OUPUT IS RA,DEC,MU,MUP IN SAME UNITS
C L IS HIGH DECLINATION FLAG
      IF(L.EQ.5) GO TO 1
      RA=ALP+T*(DA75+T*(D2A75+FT*T*(D2A75-D2A50)))
      DEC=DEL+T*(DD75+T*(D2D75+FT*T*(D2D75-D2D50)))
      MU=MUA+T*(DMU75+2.*T*(DMU75-DMU50))
      MUP=MUD+T*(DMUP75+2.*T*(DMUP75-DMUP50))
      GO TO 2
    1 RA=ALP+T*(DA75+T*(D2A75+TWT*T*(D2A75-D2A50)))
      DEC=DEL+T*(DD75+T*(D2D75+TWT*T*(D2D75-D2D50)))
      MU=MUA+T*(DMU75+10.*T*(DMU75-DMU50))
      MUP=MUD+T*(DMUP75+10.*T*(DMUP75-DMUP50))
C CHECK FOR OVER THE POLES OR AROUND THE VERNAL EQUINOX
    2 IF(DABS(DEC).LT.PI2) GO TO 5
      RA=RA+PI
      IF(DEC) 3,3,4
    3 DEC=-DEC-PI
      GO TO 5
    4 DEC=PI-DEC
    5 IF(RA.GE.TPI) RA=RA-TPI
      IF(RA.LT.0.D0) RA=RA+TPI
      RETURN
      END
```

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